CERTIFICATION

I, Yoshihiro Katsu c/o Murata Manufacturing Co., Ltd., at 26-10, Tenjin 2-chome Nagaokakyo-shi, Kyoto-fu, Japan, do hereby certify that I am conversant with the English and Japanese languages, and I further certify that to the best of my knowledge and belief the attached English translation is a true and correct translation of the Japanese patent application No. 11-362886 filed on December 21, 1999.

Signed this on the 19th day of November, 2002

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JP Application No. 11-362886

[Name of Document] SPECIFICATION

[Title of the Invention] RESONANT ELEMENT AND VIBRATION ADJUSTING METHOD THEREFOR

[Claims]

[Claim 1] A resonant element including a vibrating body vibratable in X- and Z-directions of X, Y, and Z orthogonal three-dimensions, and exciting means for causing said vibrating body to be subjected to an excitation vibration in the X-direction, said resonant element comprising:

excitation deflection detecting means for detecting the deflection of said vibrating body in the Z-direction during the excitation vibration thereof in the X-direction; and

excitation deflection inhibiting means for inhibiting the deflection of said vibrating body in the Z-direction.

[Claim 2] A resonant element as claimed in claim 1, wherein:

said resonant element constitutes an angular velocity sensor for detecting the angular velocity around a Y-axis based on the vibration of said vibrating body in the Z-direction by a Coriolis force; and

said angular velocity sensor has Z-direction vibration detecting means for detecting the vibration of said vibrating body in the Z-direction, said Z-direction vibration detecting means also serving as excitation deflection detecting means.

[Claim 3] A resonant element as claimed in claim 1 or 2,

wherein:

said excitation deflection detecting means is constituted of a detecting electrode for detecting the variation in the electrostatic capacity with respect to said vibrating body in response to the vibration thereof in the Z-direction; and

said excitation deflection detecting means detects the variation in the detected electrostatic capacity by said detecting electrode during the excitation vibration of said vibrating body in the X-direction, as a deflection of said vibrating body in the Z-direction.

[Claim 4] A resonant element as claimed in claim 1, 2, or 3, wherein:

said vibrating body is disposed so as to be opposed to the plane of an X-Y plane direction of a fixed substrate; and

said vibrating body constitutes a planar vibrating body supported by said fixed substrate via support beams so as to be vibratable in the X-direction.

[Claim 5] A method for adjusting the vibration of a resonant element including a vibrating body vibratable in X- and Z-directions of X, Y, and Z orthogonal three-dimensions, and exciting means for causing said vibrating body to be subjected to an excitation vibration in an X-direction, said method comprising:

a detecting electrode for detecting the variation in the electrostatic capacity with respect to said vibrating body in

response to the vibration thereof in the Z-direction; and

excitation deflection inhibiting means which give electrostatic attractive forces to said vibrating body and which inhibit the deflection of said vibrating body in a Z-direction during the excitation vibration thereof in the X-direction, by said electrostatic attractive forces, wherein:

the variation in the detected electrostatic capacity by said detecting electrode is detected as a deflection of said vibrating body in the Z-direction, while the vibrating body is caused to be subjected to an excitation vibration in the X-direction by said exciting means; and

said electrostatic attractive forces given to said vibrating body by said excitation deflection inhibiting means are controlled in the direction such that the variation in the detected electrostatic capacity by said detecting electrode is canceled.

[Claim 6] A method for adjusting the vibration of a resonant element as claimed in claim 5, wherein:

by converting the detected electrostatic capacity by said detecting electrode into a voltage, the deflection of said vibrating body in the Z-direction during the excitation vibration thereof in the X-direction is detected based on the variation in the voltage.

[Claim 7] A method for adjusting the vibration of a

resonant element as claimed in claim 6, wherein:

the detected electrostatic capacity by said detecting electrode is converted into a voltage using capacity-voltage converting means comprising FET.

[Claim 8] A method for adjusting the vibration of a resonant element as claimed in claim 5, 6, or 7, wherein:

said resonant element constitutes an angular velocity sensor for detecting the angular velocity around the Y-axis by a Coriolis force, based on the vibration of said vibrating body in the Z-direction;

said angular velocity sensor has Z-direction vibration detecting means for detecting the vibration of said vibrating body in the Z-direction utilizing the variation in the electrostatic capacity;

the sensor device into which said angular velocity sensor is to be built, has capacity-voltage converting means for converting the detected electrostatic capacity by said detecting electrode into a voltage;

said Z-direction vibration detecting means also serving as excitation deflection detecting means; and

said capacity-voltage converting means also serves as capacity-voltage converting means for detecting an excitation deflection.

[Detailed Description of the Invention]

[0001]

[Industrial Field of the Invention]

The present invention relates to a resonant element used as an angular velocity sensor, acceleration sensor, filter, or the like, and to a vibration adjustment method therefor.

[0002]

[Description of the Related Art]

Fig. 9(a) is a perspective view showing the resonant element previously proposed by same applicant as this application. Fig. 9(b) is a sectional view taken along the line I-I in Fig. 9(a). The resonant element shown in Figs. 9(a) and 9(b) is a resonant element 1 which is a microelement produced utilizing a conventional silicon micromachining technique and the like. The resonant element 1 are produced by forming a nitride film 3 on a silicon fixed substrate 2, then forming a polysilicon film 4 thereover, and making these films 3 and 4 a predetermined set pattern by dry etching or the like.

[0003]

As shown in Figs. 9(a) and 9(b), above the top surface 2a which is a plane in the X-Y plane direction of the fixed substrate 2, a vibrator 5 is disposed in a state isolated from the fixed substrate 2. In the resonant element 1 shown in Fig. 9, the vibrator 5 performs the function as a planar vibrating body 6. The vibrator 5 is supported via support beams 7 so as to be vibratable in the X-direction. One end side of each of

the support beams 7 is fixed to the fixed substrate 2 via a fixing portion 8.

[0004]

On the right and left sides (in the figure) of the vibrator 5, movable-side comb electrodes 10 (10a and 10b) are each formed outwardly in the transverse direction (X-direction), and fixed-side comb electrodes 11 (11a and 11b) are each disposed inwardly in the transverse direction at the positions opposed to the above-mentioned movable-side comb electrodes 10 in a state of being engaged in the comb electrodes 10 with an interval interposed. The movable-side electrodes 10 and the fixed-side comb electrodes 11 are each connected to outside electrode pads (not shown) via conductive patterns (not shown), and thereby form exciting means 12.

[0005]

For example, when AC voltages which are different in the phase from each other by 180° are each applied to the fixed-side comb electrodes 11a and 11b while maintaining the movable-side comb electrodes 10a and 10b at a predetermined constant voltage (0 volt for example), electrostatic forces in the directions opposite to each other each occur between the movable-side comb electrodes 10a and the fixed-side comb electrodes 11a, and between the movable-side comb electrodes 10b and the fixed-side comb electrodes 11b, and by this electrostatic forces, the vibrator 5 is caused to be subjected

to an excitation vibration in the X-direction.

[0006]

In the resonant element 1 with the above-described features, when the resonant element 1 is rotated around the Y-axis while being caused to be subjected to an excitation vibration in the X-direction as described above, a Coriolis force occurs in the Z-direction orthogonal to the above-mentioned X-Y plane direction. This Coriolis force is applied to the vibrator 5 (planar vibrating body 6), and the vibrator 5 vibrates in the direction of the Coriolis force. By measuring the electric signal corresponding to the magnitude of the vibration amplitude of the vibrator 5 due to the Coriolis force occurring at this time, for example, the magnitude of a rotational angular velocity can be detected.

[0007]

In the case where the resonant element 1 is used as an angular velocity sensor, there is provided a detecting portion for measuring the electric signal corresponding to the magnitude of vibration amplitude of the vibrator 5 due to a Coriolis force.

[0008]

When the resonant element 1 is produced, the resonance frequency of the vibrator 5 (planar vibrating body 6) in the direction of a Coriolis force (Z-direction) is previously set at the design stage to the resonance frequency in the X-

direction, and the shape, dimensions, weight, etc. of the vibrator 5 are designed and implemented so that the above-mentioned resonance frequency is obtained. In many cases, however, the shape, dimensions, weight, etc. of the vibrator 5 are not implemented as designed, depending on the machining accuracy of the silicon micromachining technique, and the deviation of the resonance frequency of the vibrator 5 from the designed frequency often occurs. If the vibration of the vibrator 5 is in a resonant state, the amplitude thereof is amplified by leaps and bounds by virtue of the Q (quality factor) value related to the structure, but if the frequency deviates, a problem rises that the amplitude is hardly amplified, and that the sensitivity of the resonant element is significantly reduced. It is therefore necessary to adjust the resonance frequency of the vibrator 5 to the set frequency in design by performing trimming with respect to the vibrator 5 and/or the support beams 7 by, for example, a troublesome machining.

[0009]

The resonant element 1 is, however, a minute element produced by utilizing the silicon micromachining technique. Therefore, even when trying to perform trimming utilizing machining with respect to a minute trimming adjustment portion required for obtaining a desired resonance frequency, the troublesome machining makes it substantially impossible to

perform grinding working with respect to the minute planar vibrating body 6 and/or the support beams 7 so as to have desired dimensions, shape, and weight, etc., because of the machining accuracy. It has therefore been difficult to adjust the resonance frequency of the planar vibrating body 6 to a set value.

[0010]

In the above-described proposed resonant element 1 shown in Fig. 9, therefore, a conductive layer 15 for giving an electrostatic attractive force 14 is provided on the fixed substrate 2 at the position opposed to the vibrator 5 with an interval interposed in the Z-direction, as illustrated in Figs. 9(a) and (b). As shown in Fig. 9(a), the conductive layer 15 is connected to a conductive pad 17 via a conductive pattern 16. By controlling the voltage to be applied to the conductive layer 15 via the conductive pattern 16 and conductive pad 17, the resonance frequency of the vibrator 5 has been arranged to be adjustable to an set value.

[0011]

Once a DC voltage is applied to the conductive layer 15, an electrostatic attractive force acts on the vibrator 5, and this acts on the vibrator 5 as an electrostatic spring. Specifically, when the vibrator 5 vibrates in the direction such that the vibrator 5 approaches the fixed substrate 2, the electrostatic attractive force acts in the direction such that

the amplitude is increased, so that the application of the DC voltage to the conductive layer 15 has an effect of generating a force in the direction opposite to the direction of the force of a mechanical spring. This results in a reduction in the resonance frequency of the vibrator 5 in the Z-direction. Since this reduced amount of the resonance frequency varies in accordance with the magnitude of the electrostatic attractive force 14 applied, a fine-adjustment of the resonance frequency of the vibrator 5 from the natural frequency thereof to the lower frequency side can be performed by adjusting the magnitude of the DC voltage to be applied to the conductive layer 15.

[0012]

Utilizing this effect, by previously designing the natural resonance frequency of the vibrator 5 in the Z-direction to be slightly higher than the most sensitive resonance frequency (the frequency equal to the resonance frequency in the X-direction), in other words, by previously designing the resonance frequency of the vibrator 5 in the Z-direction to be rather higher than the resonance frequency of thereof in the excitation vibrational direction by the exciting means 12, the vibrator 5 can be resonated at a predetermined resonance frequency.

[0013]

[Problems to be Solved by the Invention]

However, although the adjustment of the resonance frequency for the vibrator 5 has been performed by providing the conductive layer 15 as described above, in some cases, characteristics such as S/N ratio have deteriorated due to an increase in the noise of the resonant element 1.

[0014]

By the investigation by the present inventor into the reason for the deterioration of the characteristics, it has been found that the deterioration of characteristics is attributable to the vibrating conditions of the vibrator 5. Figs. 8(a) and (b) each show vibrating states of the vibrator 5 in the X-Z plane, the vibrating states being observed in the experiments by present inventor. If there is no angular velocity around the Y-axis when the vibrator 5 is caused to be subjected to an excitation vibration, it is desirable that vibrator 5 be subjected to an excitation vibration in the X-direction horizontally along the plane 2a in the X-Y plane direction of the fixed substrate 2, as illustrated in Fig. 10(c), and substantially without deflection in the Z-direction as shown in Fig. 8(b).

[0015]

In contrast to this, in some cases, the vibrator 5 vibrates as shown in Figs. 10(a) and 10(b), and as illustrated in Fig. 8(a), the vibrations of the vibrator 5 are in states deflecting by a large amount in the Z-direction which is the

detection direction of a Coriolis force. In such cases, the resonant element 1 has been found to deteriorate in characteristics.

[0016]

The present inventor, therefore, has noted that the deflection of the vibrator 5 in the Z-direction is attributable to the tilt of the vibrator 5 with respect to the substrate plane of the fixed substrate 2, and has proposed various resonant elements 1 each having excitation deflection inhibiting means for correcting the tilt of the vibrator 5 and for inhibiting the deflection of the vibrator 5 in the Z-direction.

[0017]

Fig. 6(a) is a perspective view showing one example of the proposed resonant elements 1, and Fig. 6(b) is a sectional view taken along the line I-I in Fig. 6(a). Here, in Figs. 6(b) and 6(b), the same components as those of the resonant element 1 in Figs. 9(a) and (b) are identified by the same reference numerals, and the repeated descriptions of the common components are omitted.

[0018]

In the resonant element 1 shown in Figs. 6(a) and 6(b), conductive layers 20 and 21 are disposed on the plane in the X-Y plane direction of he fixed substrate 2 so as to be opposed to each other with an interval in the X-direction

therebetween, and to be opposed to the right or left (in the figures) edge area with an interval interposed. The conductive layers 20 and 21 are conductively connected to conductive pads 24 and 25 via conductive patterns 22 and 23, respectively. In the resonant element 1 shown in Fig. 6, excitation deflection inhibiting means are constituted of the conductor layers 20 and 21.

[0019]

By individually applying DC voltages to the above-described conductive layers 20 and 21 via the conductive patterns 22 and 23, and the conductive pads 24 and 25, respectively, electrostatic attractive forces 26 and 27 occur between the conductive layers 20 and 21, and the vibrator 5. The tilt of the vibrator 5 can be corrected by adjusting each of the right and left electrostatic attractive forces 26 and 27 to the vibrator 5 through adjusting each of the voltages to be applied to the conductive layers 20 and 21.

[0020]

Specifically, if the vibrator 5 tilts downwardly to the right as indicated by a broken line α in Fig. 6(b), a DC voltage higher than that applied to the conductive layer 21 is applied to the conductive layer 20. Thereby, the electrostatic attractive force 26 acting on the left edge area of the vibrator 5 opposed to the conductive layer 20 becomes larger than the electrostatic attractive force 27 acting on

the right edge area of the vibrator 5 opposed to the conductive layer 21, so that the left edge area of the vibrator 5 is pulled toward the substrate 2 side more strongly than the right edge area of the vibrator 5, whereby the above-mentioned tilt is corrected.

[0021]

If the vibrator 5 tilts upwardly to the right as indicated by a broken line β in Fig. 6(b), a DC voltage higher than that applied to the conductive layer 20 is applied to the conductive layer 21. Thereby, the above-mentioned electrostatic force 27 becomes larger than the electrostatic force 26, so that the right edge area of the vibrator 5 is pulled toward the substrate 2 side more strongly than the left edge area of the vibrator 5, whereby the above-mentioned tilt is corrected.

[0022]

In the proposed resonant element 1 shown in Fig. 6, by providing the conductive layers 20 and 21 as described above, the tilt of the vibrator 5 can be corrected, which leads to an improvement in the vibrating conditions of the vibrator 5.

[0023]

Meanwhile, in order to find the optimum applied voltage to the conductive layers 20 and 21 for correcting the tilt of the vibrator 5, the present applicant has performed the following vibration adjustments for the vibrator 5, utilizing

a large-scale vibration measuring system 30 as shown in Fig. 7.

[0024]

For example, a resonant element 1 is disposed on a specimen holding stand 31, driving means (not shown) for AC voltage application is conductively connected to the above-described fixed side comb electrode 11, and first DC bias applying means 32 is conductively connected to the above-described conductive layer 20 via the electrode pad 24 and the conductive pattern 22. In the same manner, second DC bias applying means 33 is conductively connected to the above-described conductive layer 20 via the electrode pad 25 and the conductive pattern 23.

[0025]

Then, in the state wherein the vibrator 5 is caused to be subjected to an excitation vibration by the above-described driving means, the vibrator 5 under excitation vibration is radiated by a laser rays 35 from a laser displacement meter 34. By utilizing the reflected laser rays from the vibrator 5, the signals in response to displacing conditions in the X-direction and those in the Z-direction of the vibrator 5 is each output from the laser displacement meter 34 side toward an oscilloscope 36.

[0026]

The vibrating conditions of the vibrator 5 in the X-Z plane can be viewed on the screen of the oscilloscope 36.

While viewing the screen of the oscilloscope 36, a vibration adjustment operator individually varies the magnitudes of the voltages to be applied to the conductive layers 20 and 21, by controlling the above-described firs t and second DC bias applying means 32 and 33, respectively. Thereby, the vibration adjustment operator obtains the optimum values of the applied voltage to the conductive layers 20 and 21, wherein the deflection of the vibrator 5 in the Z-direction which is shown up on the screen of the oscilloscope can be eliminated, or suppressed to a very small amount.

[0027]

In this manner, vibration adjustments for the vibrator 5 utilizing the vibration measuring system 30 shown in Fig. 7 are performed.

[0028]

After the optimum values of the applied voltage to the conductive layers 20 and 21 have been obtained as described above, the above-described resonant element 1 is removed from the specimen holding stand 31 of the vibration measuring system 30, and, for example, is built into a predetermined sensor device or the like. The sensor device into which the resonant element 1 having the conductive layers 20 and 21 shown in Fig. 6 is to be built, is provided with means for individually applying DC voltages to the conductive layers 20 and 21, and the means is set so that the voltage having the

optimum value obtained are each applied to the conductive layers 20 and 21. This allows the vibrator 5 of the resonant element 1 to be subjected to an ideal excitation vibration in the X-direction without deflection in the Z-direction, and allows the resonant element 1 to be improved in characteristics.

[0029]

However, there has been a problem that, in order to obtain the above-described optimum value of the applied voltage to the conductive layers 20 and 21, a large-scale vibration measuring system 30 as described above and a great deal of equipment cost are required. Also, as described above, the vibration adjusting method for the vibrator 5 has been a manual method such that the operator obtains the optimum values of the applied voltage to the conductive layers 20 and 21 by controlling the first and second DC bias applying means 32 and 33, respectively, while viewing the screen of the oscilloscope 36. A problem has been arisen, therefore, that the vibration adjustment requires much time and a high cost.

[0030]

Furthermore, as described above, since the operator performs the vibration adjustment for the vibrator 5 based on vibration conditions (vibrational loci) of the vibrator 5 in the X-Z plane shown up on the screen of the oscilloscope 36 while viewing the screen of the oscilloscope 36, there is a

problem that an improvement in the adjustment accuracy is difficult.

[0031]

Moreover, in accordance with the vibration adjustment method as described above, after the optimum value of the applied voltage to the conductive layers 20 and 21 has been obtained by the vibration measuring system 30, the resonant element 1 is removed from the specimen holding stand 31 of the vibration measuring system 30, and is built into a predetermined sensor device or the like. Therefore, even though the optimum value of the applied voltage to the conductive layers 20 and 21 has been obtained by the vibration measuring system 30, for example, the stresses within the support beams 7 of the resonant element 1 can change when the resonant element 1 is removed from the specimen holding stand 31 and is built into a predetermined sensor device, and thereby the optimum voltage value of the applied voltage to the conductive layers 20 and 21 can change into a different voltage from the optimum voltage value obtained. In such a case, a problem arises that the vibrator 5 of the resonant element 1 in the sensor device cannot be caused to be subjected to an excitation vibration in the optimum conditions.

[0032]

If the optimum voltage value of the applied voltage to the conductive layers 20 and 21 has thus changed, it will be

necessary to again dispose the resonant element 1 in the vibration measuring system 30 and to again perform the above-described vibration adjustment. This is very troublesome, however, and it is virtually impracticable after the resonant element 1 has been built into the sensor device.

[0033]

The present invention has been made in order to solve the above-described problems. It is a first object of the present invention to allow the vibration adjustment for the vibrator for inhibiting the deflection of the vibrator (vibrating body) in the Z-direction during the excitation vibration thereof in the X-direction to be easily performed, without the need for a large-scale apparatus. It is a second object to facilitate the automation of the vibration adjustment for the vibrator. It is a third object to provide a resonant element allowing the vibration adjustment for the vibrator to be performed in the state wherein the vibrator has been built into the sensor device.

[0034]

[Means for Solving the Problems]

In order to achieve the objects, the present invention has the following constitutions as means for solving the above-described problems. In the resonant element in accordance with a first invention including a vibrating body vibratable in X- and Z-directions of X, Y, and Z orthogonal

three-dimensions, and exciting means for causing the vibrating body to be subjected to an excitation vibration in an X-direction, there are provided excitation deflection detecting means for detecting the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction, and excitation deflection inhibiting means for inhibiting the deflection of the vibrating body in the Z-direction.

[0035]

The resonant element in accordance with a second invention has the constitution of the first invention. In this second invention, the resonant element constitutes an angular velocity sensor for detecting the angular velocity around the Y-axis based on the vibration of the vibrating body in the Z-direction by a Coriolis force, and the angular velocity sensor has Z-direction vibration detecting means for detecting the vibration of the vibrating body in the Z-direction, the Z-direction vibration detecting means also serving as excitation deflection detecting means.

[0036]

The resonant element in accordance with a third invention has the constitution of the first or second invention. In this third invention, the excitation deflection detecting means is constituted of a detecting electrode for detecting the variation in the electrostatic capacity with respect to

the vibrating body in response to the vibration of the vibrating body in the Z-direction, and the excitation deflection detecting means detects the variation in the detected electrostatic capacity by the detecting electrode during the excitation vibration thereof in the X-direction, as a deflection of the vibrating body in the Z-direction.

[0037]

The resonant element in accordance with a fourth invention has the constitution of the first, second, or third invention. In this fourth invention, the vibrating body is disposed so as to be opposed to the plane of the X-Y plane direction of the fixed substrate, and the vibrating body constitutes a planar vibrating body supported by the fixed substrate via support beams so as to be vibratable in the X-direction.

[0038]

The vibration adjustment method for a resonant element in accordance with a fifth invention is a method for adjusting the vibration of a resonant element including a vibrating body vibratable in X- and Z-directions of X, Y, and Z orthogonal three-dimensions, and exciting means for causing the vibrating body to be subjected to an excitation vibration in the X-direction. The vibration adjustment method in accordance with this fifth invention comprises a detecting electrode for detecting the variation in the electrostatic capacity with

respect to the vibrating body in response to the vibration thereof in the Z-direction; and excitation deflection inhibiting means which give electrostatic attractive forces to the vibrating body and which inhibit the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction, by the electrostatic attractive forces. In the vibration adjustment method in accordance with this fifth invention, the variation in the detected electrostatic capacity by the detecting electrode is detected as a deflection of the vibrating body in the Z-direction, while the vibrating body is caused to be subjected to an excitation vibration in the X-direction by the exciting means; and the electrostatic attractive forces given to the vibrating body by the excitation deflection inhibiting means are controlled in the direction such that the variation in the detected electrostatic capacity by the detecting electrode is canceled.

[0039]

The vibration adjustment method for a resonant element in accordance with a sixth invention has the constitution of the fifth invention. In this sixth invention, by converting the detected electrostatic capacity by the detecting electrode into a voltage, the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction is detected based on the variation in the voltage.

[0040]

The vibration adjustment method for a resonant element in accordance with a seventh invention has the constitution of the sixth invention. In this seventh invention, the detected electrostatic capacity by the detecting electrode is converted into a voltage using capacity-voltage converting means comprising FET.

[0041]

The vibration adjustment method for a resonant element in accordance with a eighth invention has the constitution of the fifth, sixth, or seventh invention. In this eighth invention, the resonant element constitutes an angular velocity sensor for detecting the angular velocity around the Y-axis by a Coriolis force, based on the vibration of the vibrating body in the Z-direction; the angular velocity sensor has Z-direction vibration detecting means for detecting the vibration of the vibrating body in the Z-direction utilizing the variation in the electrostatic capacity; the sensor device into which the angular velocity sensor is to be built, has the capacity-voltage converting means for converting the detected electrostatic capacity by the detecting electrode into a voltage; the Z-direction vibration detecting means also serving as excitation deflection detecting means; and the capacity-voltage converting means also serves as capacity-voltage converting means for detecting an excitation

deflection.

[0042]

In the present invention having the above-described constitution, when performing the vibration adjustment for the resonant element 1 by providing the resonant element 1 with excitation deflection detecting means and excitation deflection inhibiting means, the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction is detected by the excitation deflection detecting means, and the excitation deflection inhibiting means are adjusted in the direction such that the deflection in the Z-direction is eliminated. Thereby, the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction can be inhibited, and the vibrating body can be caused to be subjected to an ideal excitation vibration in the X-direction. This makes it possible to avoid the problem of the characteristics deterioration of the resonant element caused by the deflection of the vibrating body in the Z-direction.

[0043]

Since the resonant element is in itself provided with the excitation deflection detecting means, there is no need for large-scale equipment for measuring the vibrating conditions of the vibrating body as described above, which leads to a reduction in equipment cost.

[0044]

Also, since the vibration adjustment for the vibrator of the resonant element can be performed in the state wherein the vibrator has been built in the sensor device, it is possible to prevent the occurrence of the above-described problem, that is, the problem that, even though the vibration adjustment for the vibrating body has been performed, for example, the stresses within the support beams supporting the vibrating body change when the resonant element 1 is built into the sensor device, and that the vibrating body of the resonant element 1 in the sensor device cannot be caused to be subjected to an ideal excitation vibration.

[0045]

[Description of the Embodiments]

Hereinbelow, the embodiments in accordance with the present invention will be described based on the drawings.

[0046]

Fig. 1 shows one embodiment of a resonant elements in accordance with the present invention, together with a vibration adjustment system characterizing the resonant element. In the descriptions of these embodiments, the same components as the above described proposed examples are identified by the same reference numerals, and the repeated explanations of the common components are omitted.

[0047]

The resonant element 1 shown in Fig. 1 can be used as an acceleration sensor, angular velocity sensor, pressure sensor, filter, or the like. The resonant element 1 has substantially the same construction as the proposed resonant element shown in Fig. 6, but this embodiment is characterized in that a detecting electrode 40 which is excitation deflection detecting means is disposed on the top surface 2a of a fixed substrate 2 so as to be opposed to a vibrator 5 which is a planar vibrating body with an interval interposed.

[0048]

Since the vibrator 5 in this illustrated embodiment is formed of polysilicon and has electric conductivity, it is possible, by forming the above-mentioned detecting electrode 40, to detect, by the detecting electrode 40, the variation in the interval between the top surface 2a of the fixed substrate 2 and vibrator 5, that is, the vibration (deflection) of the vibrator 5 in the Z-direction, as a variation in the electrostatic capacity,

[0049]

When the resonant element 1 is used as a angular velocity sensor, for example, the detecting electrode 40 similar to the above-described one is formed on the top surface 2a of the fixed substrate 2 as Z-direction vibration detecting means, in order to detect the vibration amplitude of the vibrator 5 in the Z-direction due to a Coriolis force. In such a case, the

Z-direction vibration detecting means (detecting electrode 40) also serves as excitation deflection detecting means.

[0050]

The characteristic vibration adjusting system in this embodiment shown in Fig. 1 is arranged to perform a vibration adjustment with respect to the resonant element 1 having the above-described excitation deflection detecting means (detecting electrode 40), and comprises a first DC voltage applying means 41, a second DC voltage applying means 42, capacity-voltage converting means 43, an amplifier 44, and driving means 45.

[0051]

The above-mentioned first and second DC voltage applying means 41 and 42 are conductively connected to conductive layers 20 and 21, respectively, and has a capability of applying DC voltages to the respective conductive layers 20 and 21, and a capability of changing the magnitude of the DC voltages to be applied.

[0052]

The capacity-voltage converting means 43 comprises FET 46 and a source resistor 47. As shown in Fig. 1, the gate -side of the FET 46 is conductively connected to the detecting electrode 40, one end side of the source resistor 47 is connected to the source-side of the FET 46, and the other end side of the source resistor 47 is grounded.

[0053]

In the capacity-voltage converting means 43, the voltage corresponding to the electrostatic capacity between the vibrator 5 and the detecting electrode 40 occurs at the connection portion P between the source-side of the FET 46 and the source resistor 47. In other words, the capacity-voltage converting means 43 converts the electrostatic capacity between the vibrator 5 and the detecting electrode 40 into a voltage and outputs it from the above-mentioned connection portion (output portion) P. The amplifier 44 is connected to the output portion P of the capacity-voltage converting means 43, and the amplifier 44 amplifies and outputs the voltage corresponding to the electrostatic capacity between the vibrator 5 and the detecting electrode 40, the voltage being output by the output portion P.

[0054]

In the vibration adjusting system in this illustrated embodiment, since the capacity-voltage converting means 43 is provided, and can converts the electrostatic capacity detected by the detecting electrode 40 into a voltage and output, as described above, the vibration (deflection) of vibrator 5 in the Z-direction can be detected as a voltage variation.

[0055]

The driving means 45 comprises an AC power source 48 and a phase inversion portion 49. One of the fixed-side comb

electrodes 11a and 11b of the resonant element 1 is conductively connected to the above-mentioned AC power source 48 directly, and the other is conductively connected to the AC power source 48 via the phase inversion portion 49. By this driving means 45, AC voltages which are different in the phase from each other by 180° are each applied to the fixed-side comb electrodes 11a and 11b of the resonant element 1, and thereby the vibrator 5 can be caused to be subjected to an excitation in the X-direction.

[0056]

The resonant element 1 and the vibration adjusting system shown in Fig. 1 are constituted as described above. Hereinbelow, a brief description will be made of one example of vibration adjusting methods for the resonant element 1 utilizing the characteristic vibration adjusting system in this embodiment. For example, firstly the resonant element 1 is built into the above-described vibration adjusting system, and an oscilloscope (not shown) is conductively connected to the output-side of the amplifier 44 shown in Fig. 1. The vibrator 5 is caused to be subjected to an excitation vibration in the X-direction, and the waveform of the voltage output by the amplifier 44 are viewed on the screen of the oscilloscope.

[0057]

In some cases, even though no angular velocity around the

Y-axis is applied during the excitation vibration of the vibrator 5, a voltage waveform as indicated by a solid line A in Fig. 2 is viewed with the oscilloscope, the voltage waveform being varying in response to the excitation vibration of the vibrator 5 in the X-direction.

[0058]

In such a case, since the deflection in the Z-direction is arising during the excitation vibration of the vibrator 5, a vibration adjustment for the vibrator 5 is performed. For example, while viewing the voltage waveforms shown up on the screen of the oscilloscope, the DC voltages to be each applied to the conductive layers 20 and 21 are varied by controlling the first DC voltage applying means 41 or the second DC voltage applying means 42. The applied voltages for the conductive layers 20 and 21 at the time when the voltage waveform on the screen of the oscilloscope becomes a waveform wherein substantially no vibration amplitude can be seen and wherein the voltage converges into a given voltage, as indicated by the dot line B in Fig. 2, in other words, the applied voltages for the conductive layers 20 and 21 at the time when the variation in the detected electrostatic capacity by the detecting electrode 40 disappears, or is substantially removed, is detected as the voltage optimum for the vibration adjustment for the vibrator 5.

[0059]

Specifically, when a voltage waveform indicated by the solid line A in Fig. 2 is shown up on the screen of the oscilloscope, for example, in the state wherein the conductive layer 20 of the resonant element 1 is maintained at a given voltage (0 volt for example), the applied voltage for the conductive layer 21 is varied by variably controlling the second voltage applying means 42 while viewing the voltage waveform shown up on the screen of the oscilloscope. The voltage at the time when the voltage waveform on the screen of the oscilloscope converges into a waveform wherein substantially no vibration amplitude can be seen, as indicated by a dot line B in Fig. 2, is detected as the optimum voltage for the conductive layer 21. This detected optimum voltage for the conductive layer 21, and the fixed voltage (0 volt for example) of the above-described conductive layer 20 are detected as the voltages optimum for the vibration adjustment for the vibrator 5.

[0060]

Conversely, of course, the applied voltage for the conductive layer 20 is varied in the state wherein the conductive layer 21 is maintained at a given voltage (0 volt for example), and the voltage at the time when the voltage waveform on the screen of the oscilloscope converges into a vibration amplitude wherein substantially no vibration amplitude can be seen, as indicated by a dot line B in Fig. 2,

may be detected as the optimum voltage for the conductive layer 20, whereby the voltage optimum for the vibration adjustment for the vibrator 5 is detected. Or, the voltage optimum for the vibration adjustment for the vibrator 5 may be detected by individually varying the applied voltages for the conductive layers 20 and 21 and thereby obtaining the optimum voltages to the conductive layers 20 and 21.

[0061]

As described above, by performing the vibration adjustment for the vibrator 5 through controlling the applied voltage to the conductive layers 20 and 21, the vibrator 5 can be caused to be subjected to an ideal excitation vibration substantially without deflection in the Z-direction.

[0062]

The above-described effect has been verified in the experiments by the present inventor. In these experiments, the present inventor has built the resonant element 1 having a characteristic construction in this embodiment into the vibration adjusting system shown in Fig. 1, and in the state wherein the conductive layer 20 is fixed at a given voltage (0 volt for example), the inventor has investigated as to how the voltage waveform output by the output portion P of the above-described capacity-voltage converting means varies as the applied voltage V21 to the above-described conductive layer 21 is varied.

[0063]

Fig. 3 is a graph illustrating the experimental results. In Fig. 3, the horizontal axis designates the applied voltage to the conductive layer 21, and the vertical axis designates the amplitude of the voltage waveform output by the output portion P of the capacity-voltage converting means 43. In the above-described experiments, the detecting electrode 40 has a dimensions of 0.5 × 0.5 mm, and the interval between the detecting electrode 40 and the vibrator 5 is 2 μm. The vibrator 5 is caused to be subjected to an excitation vibration in the X-direction under the frequency of 7.623 kHz.

[0064]

As shown in Fig. 3, as the applied voltage V21 to the above-described conductive layer 21 is varied, the amplitude of the voltage waveform output by the output portion P of the capacity-voltage converting means 43 varies, and the amplitude of the voltage waveform at the output portion P is minimized at the point Q (the above-mentioned applied voltage V21 is 9.34 V) shown in Fig. 3. In accordance with the investigated movement of the vibrator 5 in the X-Z plane, the vibrator 5 exhibited loci as shown in Fig. 8(b). That is, as illustrated in Fig. 10(c), the vibrator 5 was being subjected to an excitation vibration horizontally in the X-direction along the plane of the fixed substrate in the X-Y plane direction, and substantially without deflection in the Z-direction.

[0065]

As shown in these experimental results, by performing the vibration adjustment for the vibrator 5 so that the variation in the detected electrostatic capacity by the detecting electrode 40 is canceled, the vibrator 5 can be caused to be subjected to an excitation in the X-direction.

[0066]

Fig. 4 shows one example of a main circuit configuration of the sensor device 50 into which a resonant element 1 as an angular velocity sensor has been built. In the sensor device 50, the vibrator 5 is caused to be subjected to an excitation vibration in the X-direction, by each applying AC voltages which are different in the phase from each other by 180° to the fixed-side comb electrodes 11a and 11b of the resonant element 1 by driving means 45. During this an excitation vibration of the vibrator 5, once the vibrator 5 is subjected to a detecting vibration in the Z-direction by a Coriolis force due to the angular velocity around the Y-axis, the variation in the electrostatic capacity with respect to the vibrator 5 in response to the detecting vibration of the vibrator 5 in the Z-direction is output by the detecting electrode 40, and the electrostatic capacity is converted into a voltage. The voltage after the conversion is amplified by the amplifier 44, and is applied to a phase detection portion 53 via a BPF (band-pass filter) 51 and a phase shifter 52.

[0067]

The phase detection portion 53 takes in the AC voltage output by an AC power source 48 as a reference signal, and performs a phase detection with respect to the voltage applied by the phase shifter portion 52, utilizing the reference signal. The signal obtained by this phase detection is output as an detecting signal for angular velocity around the Y-axis via a LPF (low-pass filter) and the amplifier 55.

[0068]

As shown in Fig. 4, the above-described angular velocity sensor 50 has the first and second AC voltage applying means 41 and 42, the capacity-voltage converting means 43, the amplifier 44, and the driving means therein built. These allows the vibration adjusting system shown in Fig. 1 to be constructed. Therefore, when performing an vibration adjustment for the resonant element 1 as an angular velocity sensor, it is possible, after building the resonant element 1 into the sensor device 50, to utilize, for vibration adjustment, the above-described first and second AC voltage applying means 41 and 42, the capacity-voltage converting means 43, the amplifier 44, and the driving means to perform a vibration adjustment for the resonant element 1.

[0069]

In accordance with this embodiment, since the resonant element 1 is constituted so as to have a detecting electrode

40, and to detect the deflection of the vibrator 5 in the Z-direction by this detecting electrode utilizing the variation in the electrostatic capacity, the vibration adjustment can be performed by a simple vibration adjusting system shown in Fig. 1, without the need to use a large-scale vibration measuring system shown in Fig. 7.

[0070]

Since the vibration adjustment for the vibrator 5 can be easily performed, the time required for the vibration adjustment for the vibrator 5 can be reduced, and the adjustment cost can be cut down. Also, since this embodiment is constituted so that the deflection of the vibrator 5 in the Z-direction is detected utilizing the variation of the electrostatic capacity, the deflection of the vibrator 5 in the Z-direction can be detected with a much higher accuracy than the case where the deflection of the vibrator 5 in the Z-direction is detected utilizing the laser rays as described above. This results in an improvement in the accuracy of the vibration adjustment for the vibrator 5.

[0071]

Furthermore, in addition to having a simple construction, the characteristic vibration adjusting system in this embodiment has features, as described above, such as to detect the deflection of the vibrator 5 in the Z-direction utilizing the variation in the electrostatic capacity, to convert the

electrostatic capacity into a voltage, and to detect the variation in the electrostatic capacity based on the variation in the voltage. Therefore, the automation of the vibration adjustment wherein the optimum value of the applied voltages for the above-described conductive layers 20 and 21 are obtained utilizing the variation in the voltage in response to the deflection of the vibrator 5 in the Z-direction, can be easily achieved.

[0072]

Moreover, in the case of an angular velocity sensor, since there is provided Z-direction vibration detecting means (detecting electrode 40) for detecting the vibration of the vibrator 5 in the Z-direction due to a Coriolis force, the Z-direction vibration detecting means can be caused to do double duty as excitation deflection detecting means for vibration adjustment. Thereby, the vibration adjustment can be performed easily and with a high accuracy as describe above without the need to change the design.

[0073]

In addition, since the main construction portion constructing the vibration adjusting system shown in Fig. 1 is incorporated in the sensor device 50 into which the resonant element 1 as an angular velocity sensor is to be built, the vibration adjustment of the angular velocity sensor can be performed in the state wherein the angular velocity sensor has

been built into the sensor device 50. This make it possible to prevent the occurrence of the problem that, even though the vibration adjustment has been performed, for example, the stresses within the support beams 7 of the vibrator 5 change when the resonant element 1 is built into the sensor device 50, and that the optimum applied voltage to the conductive layers 20 and 21 changes with the result that the vibrator 5 of the angular velocity sensor cannot be appropriately caused to be subjected to an excitation vibration without deflection in the Z-direction.

[0074]

The present invention is not limited to the above-described embodiment, but various embodiments may be adopted. For example, in the above-described embodiment, the detecting electrode 40 is disposed on the fixed substrate 2, but, for example, when there is a cover member covering the upper side of the vibrator 5 with an interval interposed, the detecting electrode 40 may be disposed at the area opposed to the vibrator 5 on the cover member. Or, the detecting electrodes 40 may be provided on both of the fixed substrate 2 and the cover member. The same goes for the conductive layers 20 an 21. That is, the conductive layers 20 and 21 may be provided not only on the fixed substrate, but also on the above-mentioned cover member, or may be provided on both of the fixed substrate 2 and the cover member.

[0075]

Also, the detecting electrode 40 is disposed so as to be opposed to the central area of the vibrator 5 with an interval interposed, but, for example, the detecting electrodes 40 may be disposed so as to be opposed to both edge areas of the vibrator 5 with an interval in the X-direction therebetween.

[0076]

Also, the configuration of the resonant element 1 is not limited to that of the above-described embodiment illustrated. The present invention can be applied to resonant element 1s having various configurations. For example, the present invention can be applied to the resonant element 1 as shown in Fig. 5. In Figs. 5(a) and 5(b), a cavity (depression) 57 is formed in the top surface 2a which is a plane in the X-Y plane direction of the fixed substrate of glass. The bottom surface 57a of this cavity 57 forms a plane in the X-Y plane direction, as in the case of the top surface, and a planar vibrating body 6 is disposed so as to be opposed to the bottom surface 57a with an interval interposed in the Z-direction.

[0077]

The planar vibrating body 6 shown in Fig. 5 is a combined body wherein a weight 9 is connected to the inside of frame body 60 by four connection beams (detecting beams) 61. The weight has a square shape, and each of the connection beams has a L-letter shape. The tips of the shorter sides 62 of the

L-letter shaped connection beams 61 each communicates with and connected to the four corners of the weight 9.

The longer sides 63 of the L-letter shaped connection beams 61 are each extended from the shorter sides 62 side along the sides of the frame body 60 via an interval, and the tips of the extension portions thereof are each communicates with and connected to the corners of the frame body 60.

[0078]

A plurality of fixing portions 8 (four fixing portions in the figure) is each fixedly disposed on the fixed substrate 2 with intervals therebetween so as to surround the planar vibrating body 6 as described above, and the planar vibrating body 6 is fixedly supported by hooked-claw shaped support beams (driving beams) 7 so as to be vibratable in the X-direction.

[0079]

On both right and left sides (in the figure) of the planar vibrating body 6, movable-side comb electrodes 10 (10a and 10b) are formed outwardly in the X-direction, and fixed-side comb electrodes 11 (11a and 11b) are each extended from the fixing portion 64 so as to be engaged with the above-mentioned movable-side comb electrodes 10 with an interval interposed. These movable-side comb electrodes 10 and fixed-side comb electrodes 11 make up exciting means.

[0080]

The resonant element 1 shown in Fig. 5 has the featured as described above. In such a resonant element 1, similarly to the case of the above-described embodiment, there are provided conductive layers 20 and 21, and detecting electrode 40 which is excitation deflection detecting means for detecting the deflection of the weight 9 (planar vibrating body 6) in the Z-direction, and by performing vibration adjustment, the weight 9 (planar vibrating body 6) can be caused to be subjected to an ideal excitation vibration.

[0081]

[Advantages]

In accordance with the present invention, since the resonant element is provided with the excitation deflection inhibiting means, but also the resonant element is in itself provided with the excitation deflection detecting means, the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction can be detected, and the deflection of the vibrating body in the Z-direction can be inhibited by the above-described excitation deflection inhibiting means, without the need for large-scale equipment for measuring the vibrating conditions of the vibrating body. Thereby, the vibrating body can be caused to be subjected to an ideal excitation vibration in the X-direction without deflection in the Z-direction, and hence it is easy to improve characteristics of the resonant element.

[0082]

In the resonant element constituting an angular velocity sensor, since it is possible to make the Z-direction vibration detecting means to do double-duty as excitation vibration deflection detecting means, a resonant element having superior characteristics can be provided without a large change in design.

[0083]

In the excitation vibration deflection detecting means constituted of detecting means for the variation in the electrostatic capacity with respect to the vibrating body in response to the vibration thereof in the Z-direction, since the deflection of the vibrating body in the Z-direction can be detected with a high accuracy by a very simple construction, it is possible to inhibit more surely the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction, which allows a resonant element having more excellent characteristics to be provided.

[0084]

In the vibrating body which is a planar vibrating body disposed so as to be opposed to the plane in the X-Y plane direction and supported by the fixed substrate so as to be vibratable in the X-direction, since the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction has a significant adverse

effect on characteristics of the resonant element, it is very effective to provide the above-described constructions characterizing the present invention.

[0085]

In the vibration adjustment method for a resonant element comprising a detecting electrode for detecting the variation in the electrostatic capacity with respect to the vibrating body in response to the vibration of the vibrating body in the Z-direction; and excitation deflection inhibiting means which give electrostatic attractive forces to the vibrating body and which inhibit the deflection of the vibrating body in the X-direction by the electrostatic attractive forces, wherein the variation in the detected electrostatic capacity by the detecting electrode is detected as a deflection of the vibrating body in the Z-direction during the excitation vibration in the X-direction, and wherein the electrostatic attractive forces given to the vibrating body by the excitation deflection inhibiting means are controlled in the direction such that the variation in the detected electrostatic capacity by the detecting electrode is canceled, the deflection of the vibrating body in the Z-direction can be detected with a high accuracy by a very simple construction, as described above. It is therefore possible to perform a vibration adjustment for the vibrating body without the need for a large-scale equipment, which eliminates the need for a

great deal of equipment cost and reduces adjustment cost.

[0086]

In the resonant element in accordance with the present invention wherein the detected electrostatic capacity by the detecting electrode is converted into a voltage utilizing the capacity-voltage converting means having FET, or the like, and wherein the deflection of the vibrating body in the Z-direction is detected based on the variation in the voltage, it is possible to further increase the accuracy of vibration adjustment for the vibrating body, and to easily perform a vibration adjustment for the vibrating body, which leads to a reduction in the time required for the vibration adjustment for the vibrating body.

[0087]

In the resonant element in accordance with the present invention wherein the resonant element constitutes an angular velocity sensor, and wherein the Z-direction vibration detecting means and the capacity-voltage converting means incorporated in the sensor device into which the angular velocity is to be built, also serve a function of vibration adjustment, since the vibration adjustment for the vibrator can be performed in the state wherein the vibrator has been built in the sensor device, it is possible to prevent the occurrence of the problem that the deflecting state of the vibrating body in the Z-direction becomes different from that

at the time of vibration adjustment by working of building of the angular velocity sensor into the sensor device after a vibration adjustment, and that the deflection of the vibrating body in the Z-direction during the excitation vibration thereof in the X-direction occurs despite of a performed vibration adjustment.

[Brief Description of the Drawings]

[Fig. 1]

Fig. 1 is an explanatory view showing an embodiment of a resonant element in accordance with the present invention, together with the main construction of a characteristic vibration adjusting system.

[Fig. 2]

Fig. 2 is a graph showing an example of the voltage waveform in response to the electrostatic capacity between a vibrator and a detecting electrode.

[Fig. 3]

Fig. 3 is a graph showing an example of the variation in the voltage in response to the electrostatic capacity between a vibrator and a detecting electrode in accordance with the variation in the applied voltage to conductive layers.

[Fig. 4]

Fig. 4 is an explanatory view showing an example of a main circuit configuration of the sensor device into which a resonant element as an angular velocity sensor is to be built.

[Fig. 5]

Fig. 5 is an explanatory view showing another embodiment of a resonant element.

[Fig. 6]

Fig. 6 is an explanatory view illustrating a proposed example of a resonant element.

[Fig. 7]

Fig. 7 is a model diagram illustrating an example of a proposed systems performing the vibration adjustment for a resonant element used by the present applicant.

[Fig. 8]

Fig. 8 is an explanatory view illustrating an example of a vibrating state of a vibrating body in a X-Z plane.

[Fig. 9]

Fig. 9 is an explanatory view illustrating another proposed example of a resonant element.

[Fig. 10]

Fig. 10 is an explanatory view illustrating movements of a vibrating body in the X-Z plane.

[Reference Numerals]

1: resonant element

2: fixed substrate

5: vibrator

7: support beam

9: weight

10: movable-side comb electrode

11: fixed-side comb electrode

20 and 21: conductive layers

40: detecting electrode

41: first DC voltage applying means

42: second DC voltage applying means

43: capacity-voltage converting means

46: FET

50: sensor device

JP Application No. 11-362886

[Name of Document] ABSTRACT

[Abstract]

[Object] To allow the vibration adjustment for the vibrator 5 of a resonant element 1 to be easily performed.

[Solving Means] The resonant element 1 has a detecting electrode 40 disposed so as to be opposed to a vibrator 5 with an interval interposed in a Z-direction. Also, the resonant element 1 has conductive layers 20 and 21 for correcting the tilt of the vibrator 5 with respect to the substrate plane of a fixed substrate 2. The detecting electrode 40 detects the electrostatic capacity between the detecting electrode 40 and the vibrator 5, and capacity-voltage converting means 43 converts the detected electrostatic capacity into a voltage and outputs it from a output portion P. If the vibrator 5 deflects in the Z-direction although no angular velocity around a Y-axis occurs during the excitation vibration of the vibrator 5 in the X-direction, the voltage of the output portion P will vary in response to the above-mentioned deflection in the Z-direction. The vibration adjustment for the vibrator 5 is performed by variably controlling the applied voltage to the conductive layers 20 and 21 in the direction such that the deflection of the voltage of the output portion P converges.

[Selected Figure] Fig. 1